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Diagnostic Techniques for Multiphase Blast Fields

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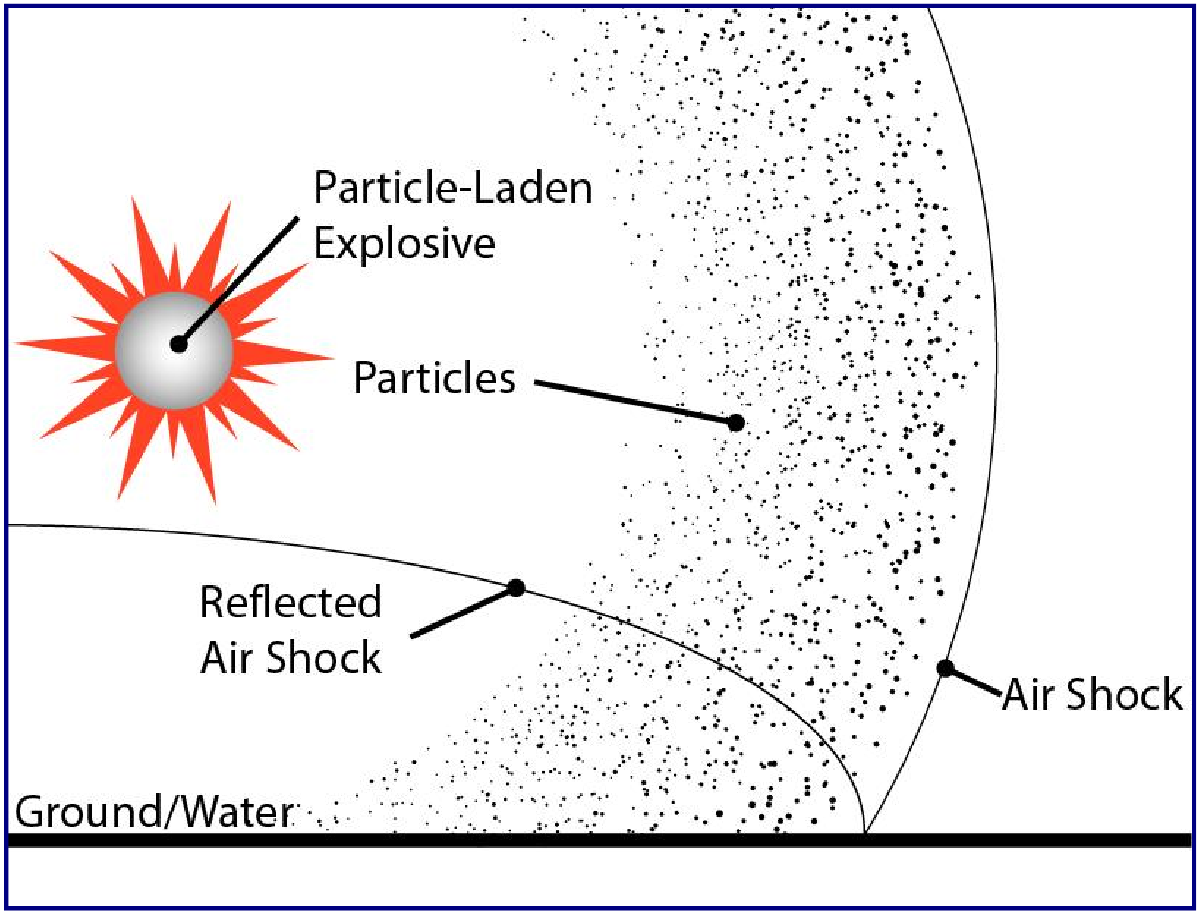
ulti-Phase Blast Flows

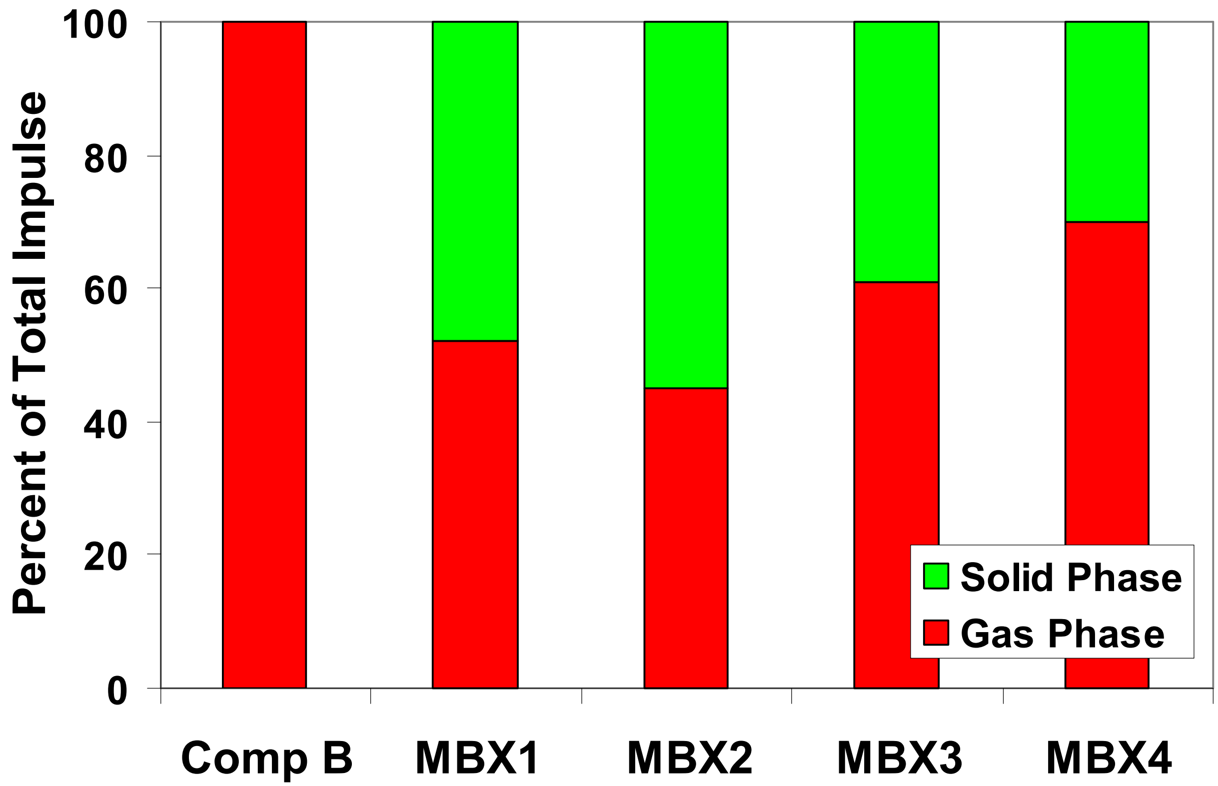
- Multi-Phase Blast Flows are produced by particle-laden explosives
- Can also be produced when a standard explosive entrains dust and debris
- A key unknown is how much energy/momentum is transported in each phase within the blast field



Typical MBX Blast Field

...ve Amounts of Momentum ...ux in MBX Blast Flows

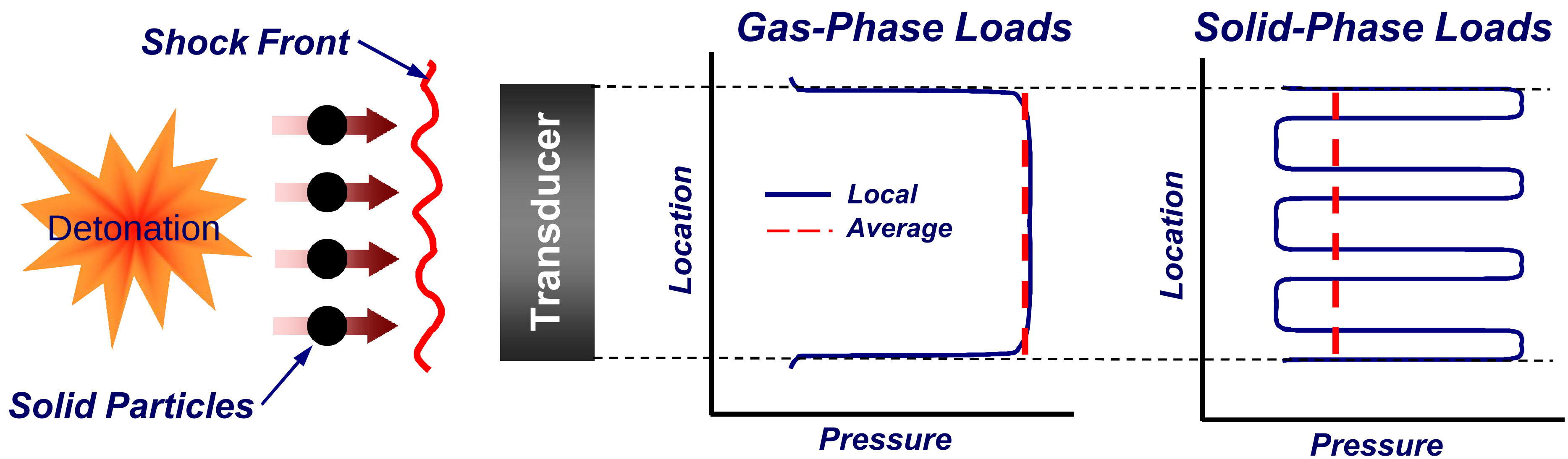
Measurements of Momentum Transfer Against a Flat-Plate Target for Four Types of Multiphase Blast Explosives (MBX)



- The solid-phase component of MBX blast fields carries a substantial amount of momentum and energy
  - Can be as much as 50% for some blast flows
- As a consequence, characterization of this class of multiphase flows must accurately account for the solid phase

Diagnostic Techniques

asurement Problem for Multi-Phase Blast Flows

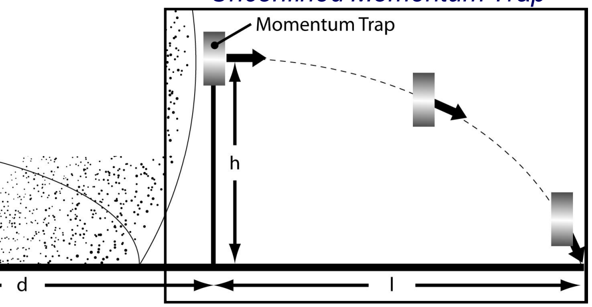


- Most pressure transducers are designed under the assumption of rough equivalence between small-scale, local loads and global, average loads
  - Good assumption for gas-phase loads because the impulse associated with individual molecular impacts is extremely small
- Not valid for distributed solid-phase loads
  - Local loads much larger than global average

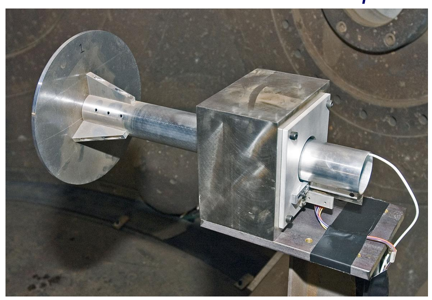
ily of Diagnostic Techniques

Impulse Traps

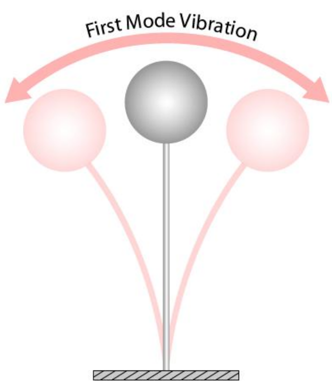
Unconfined Momentum Trap



Confined Momentum Trap



Cantilevered Ball Gauge



Inverted Ballistic Pendulum

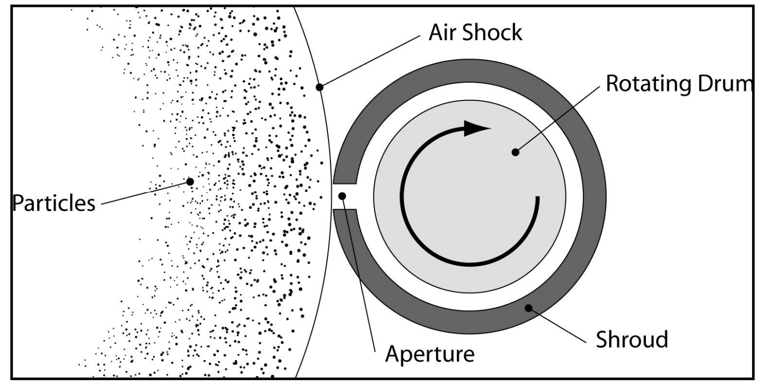
ÅNo time history information available

ÅEasy to deploy

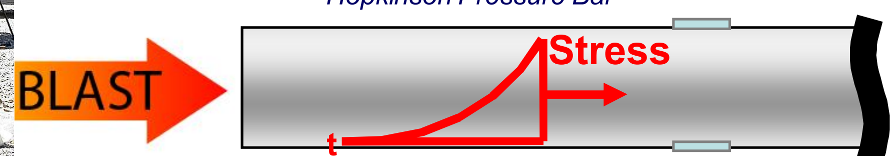
ÅSimple physics

Time-Varying Diagnostics

Particle Streak Recorder



Hopkinson Pressure Bar

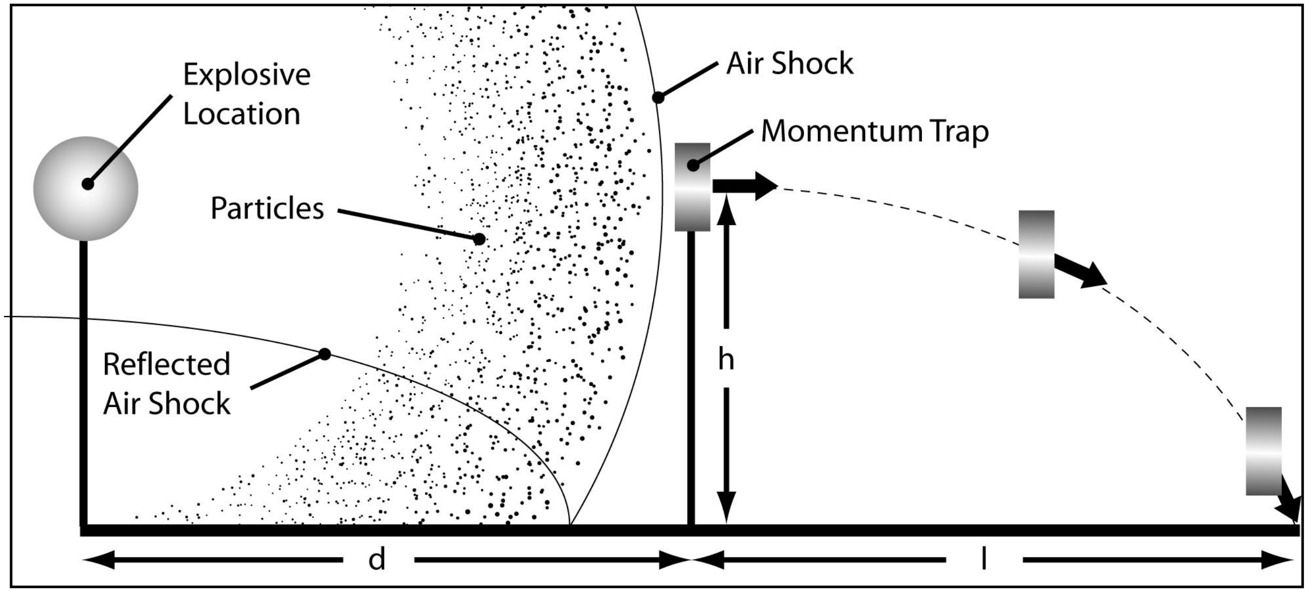


ÅProvide time history information

ÅSomewhat difficult to deploy

ÅRequires assumption-laden post-processing

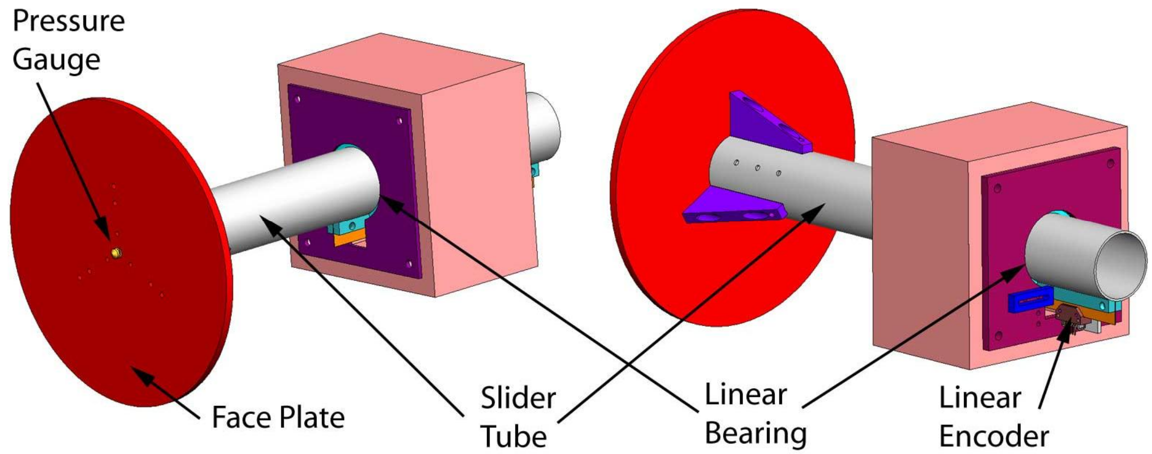
Unconfined Momentum Trap (UMT)

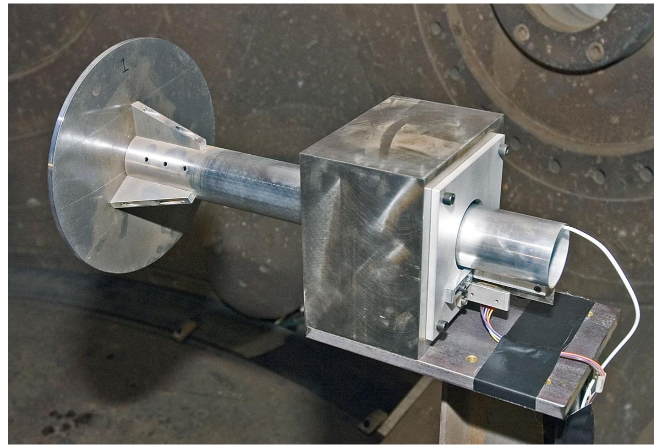


$$I = \frac{m_b l}{\sqrt{2h/g}}$$

- The Unconfined Momentum Trap (UMT) is a disk placed normal to the charge at some height
- The distance the trap is thrown is proportional to the impulse delivered to the face
  - Assumes time scales associated with loads are much less than time scales associated with loading
  - Neglects drag
- Different shapes can be used to provide information regarding target geometry effects

Confined Momentum Trap





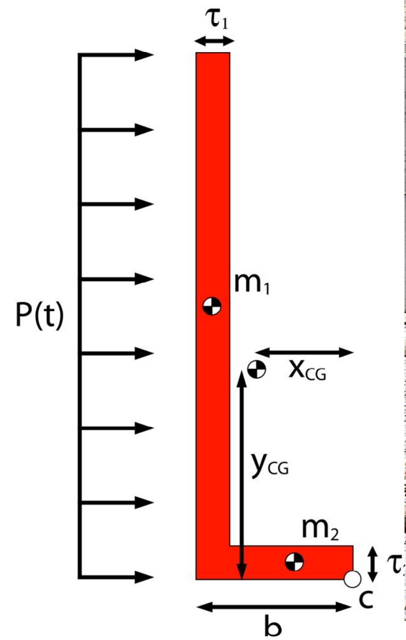
Å Uses a disc on a slider tube with optical position encoder

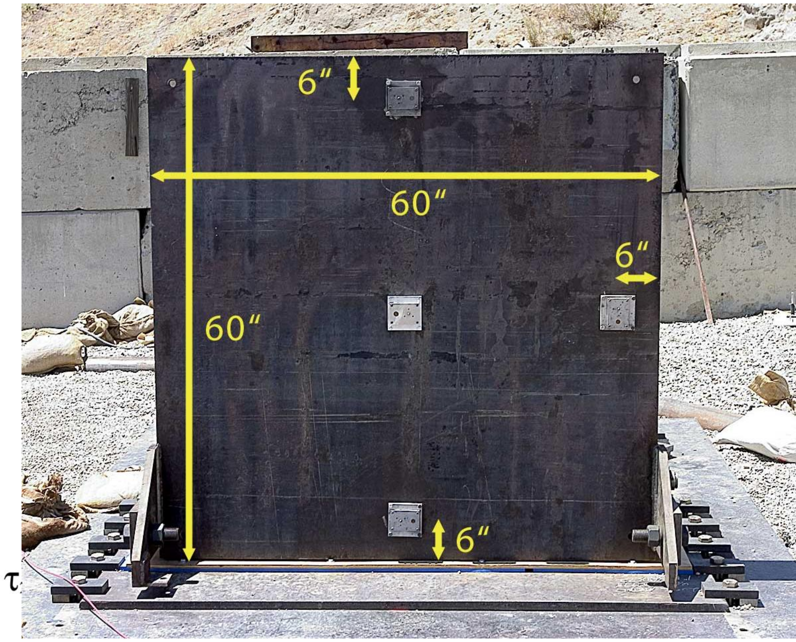
Å The time-history of the motion provides a measure of the impulse delivered to the Face Plate

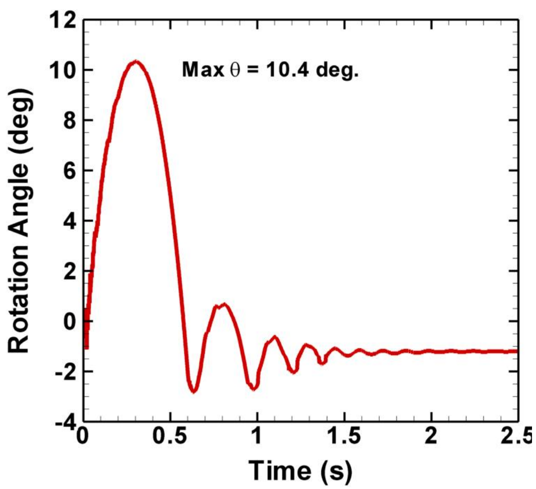
Å Face plate also includes a pressure gauge so that gas-phase loads may be measured

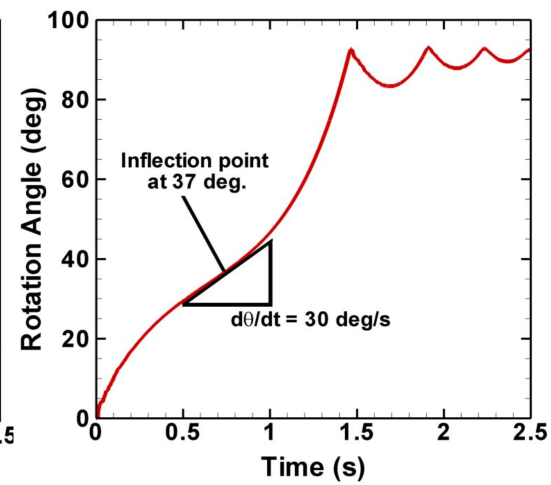
erted Ballistic Pendulum (IBP)

- Å The IBP is a large flat plate on a pivoting base
- Å Tip angle is proportional to impulse
- Å If the wall tips over the impulse is measured by the angular speed as the CG passes vertically over the pivot







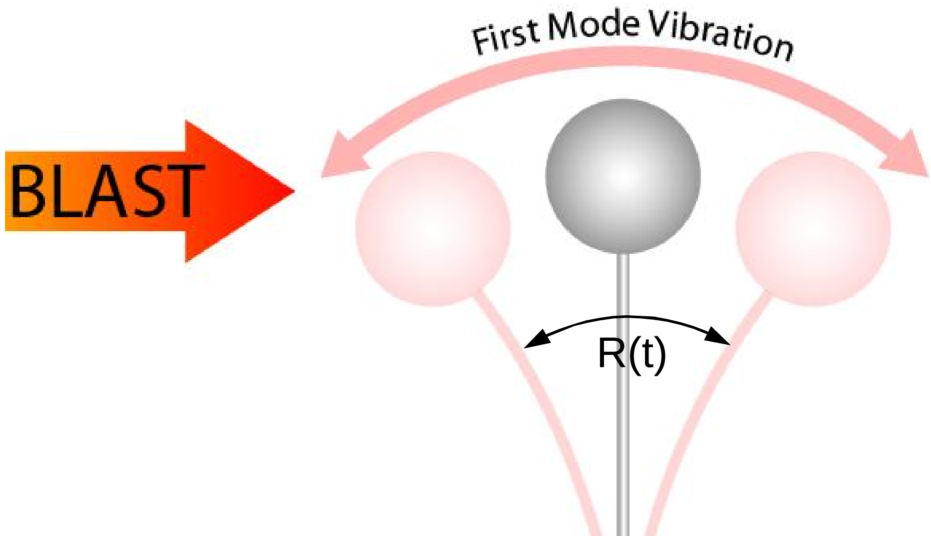


$$\theta < \theta_{tip} \qquad I = \left[\frac{8(m_1+m_2)gJ_c\left(\sqrt{x_{cg}^2+y_{cg}^2}\,\sin(\theta+\theta_0)-y_{cg}\right)}{h^4 w^2}\right]^{\frac{1}{2}}$$

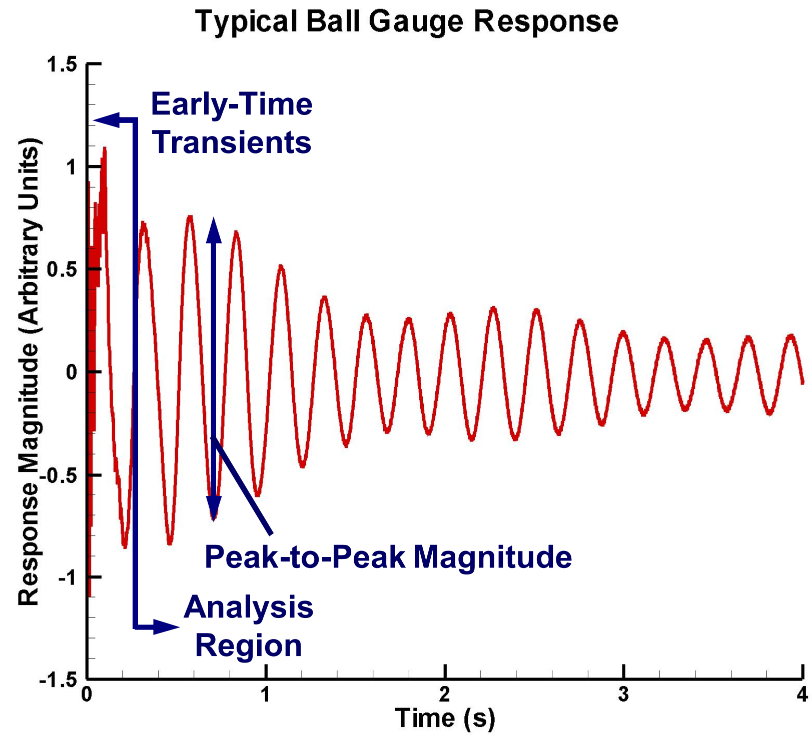
$$\theta > \theta_{tip} \qquad I = \left[\frac{8J_c}{h^4 w^2}\left[(m_1+m_2)g\left(\sqrt{x_{cg}^2+y_{cg}^2}-y_{cg}\right)+\frac{1}{2}J_C\dot{\theta}_{IP}^2\right]\right]^{\frac{1}{2}}$$

$$\theta = \theta_{tip} \qquad I_{min} = \left[\frac{8(m_1+m_2)gJ_c\left(\sqrt{x_{cg}^2+y_{cg}^2}-y_{cg}\right)}{h^4 w^2}\right]^{\frac{1}{2}}$$

e Cantilevered Ball Gauge

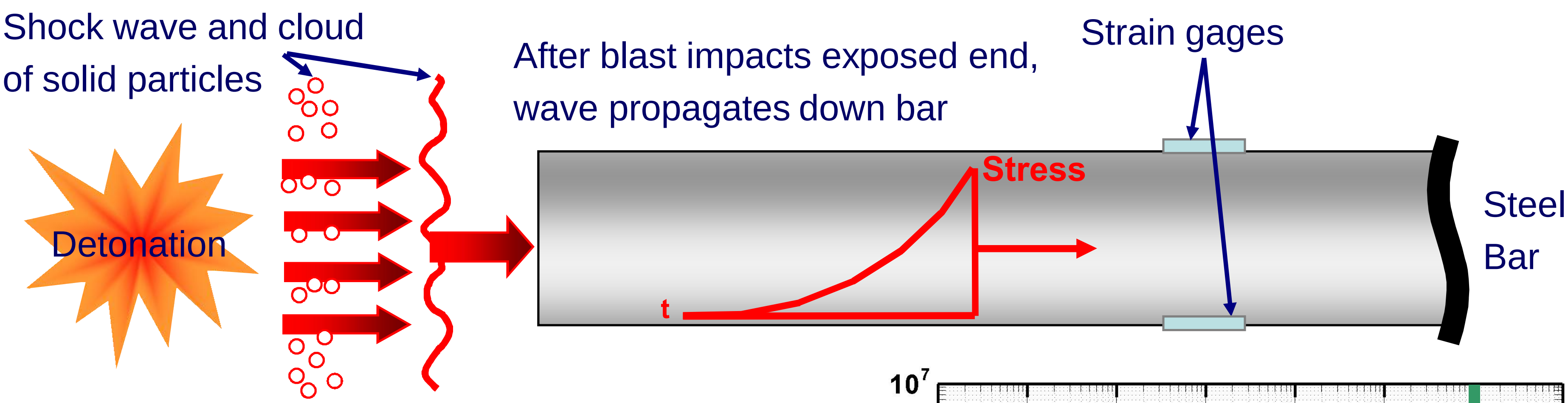


$$R(t) = Ae^{-t/\tau}\sin(\omega_n t - \phi)$$



- ÅMeasures the total impulse delivered to a sphere on a slender rod via strain measurements that capture the vibratory motion
- ÅMeasurements taken in orthogonal directions in order to compute total loading in a plane normal to the sting mount
- ÅUnder the assumption that the loading time scales << structural response time scales, total impulse is proportional to the magnitude of the structural response in the first bending mode

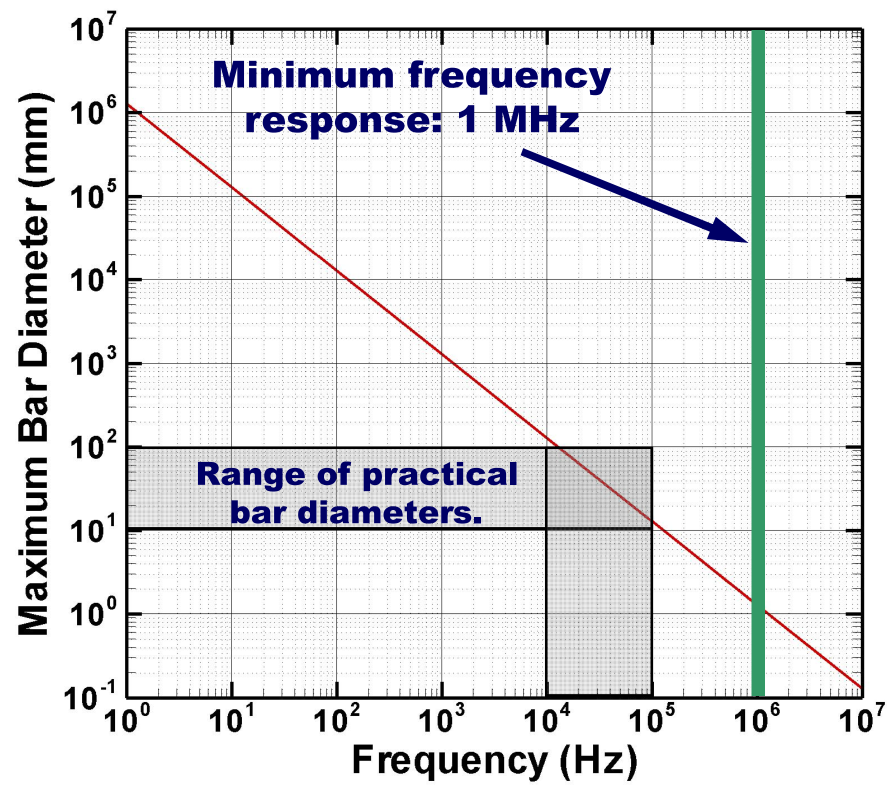
The Hopkinson Bar



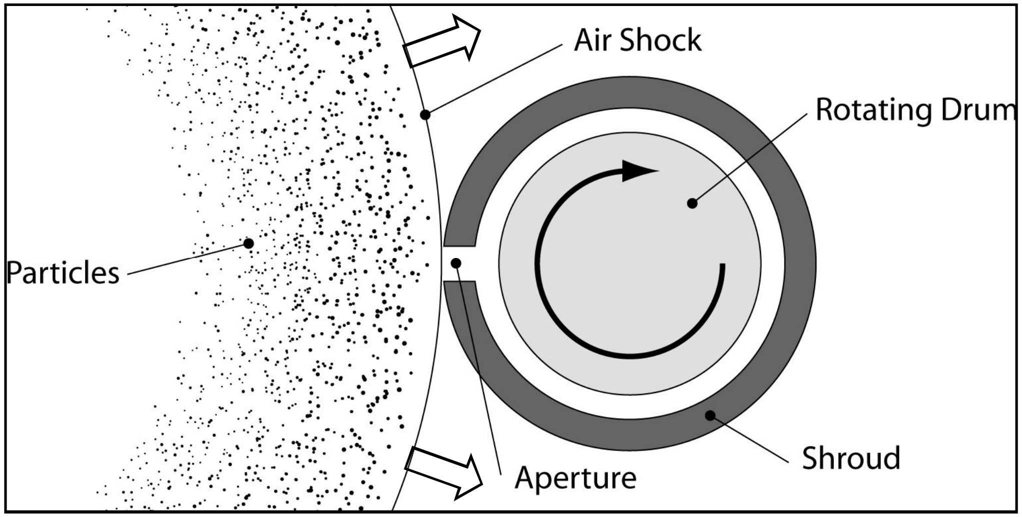
$$r < \frac{0.465 c_0}{2\pi \upsilon f}$$

For less than 5% dispersion.

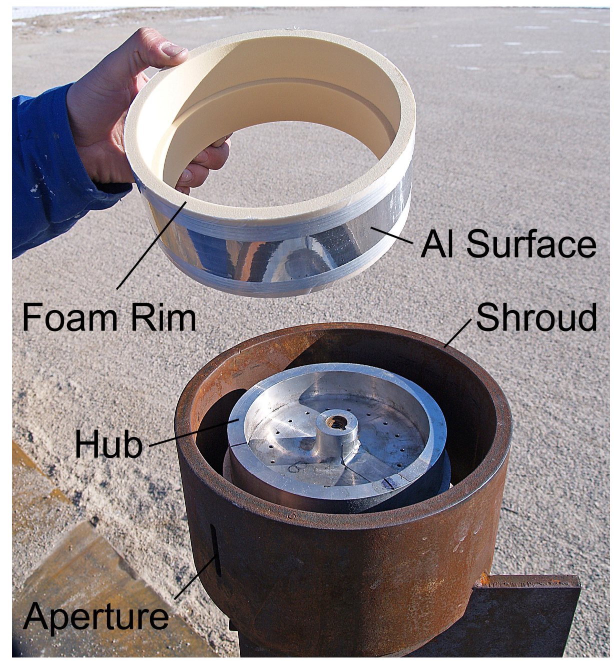
- High Frequency components of the load move more slowly through the bar, altering the signal



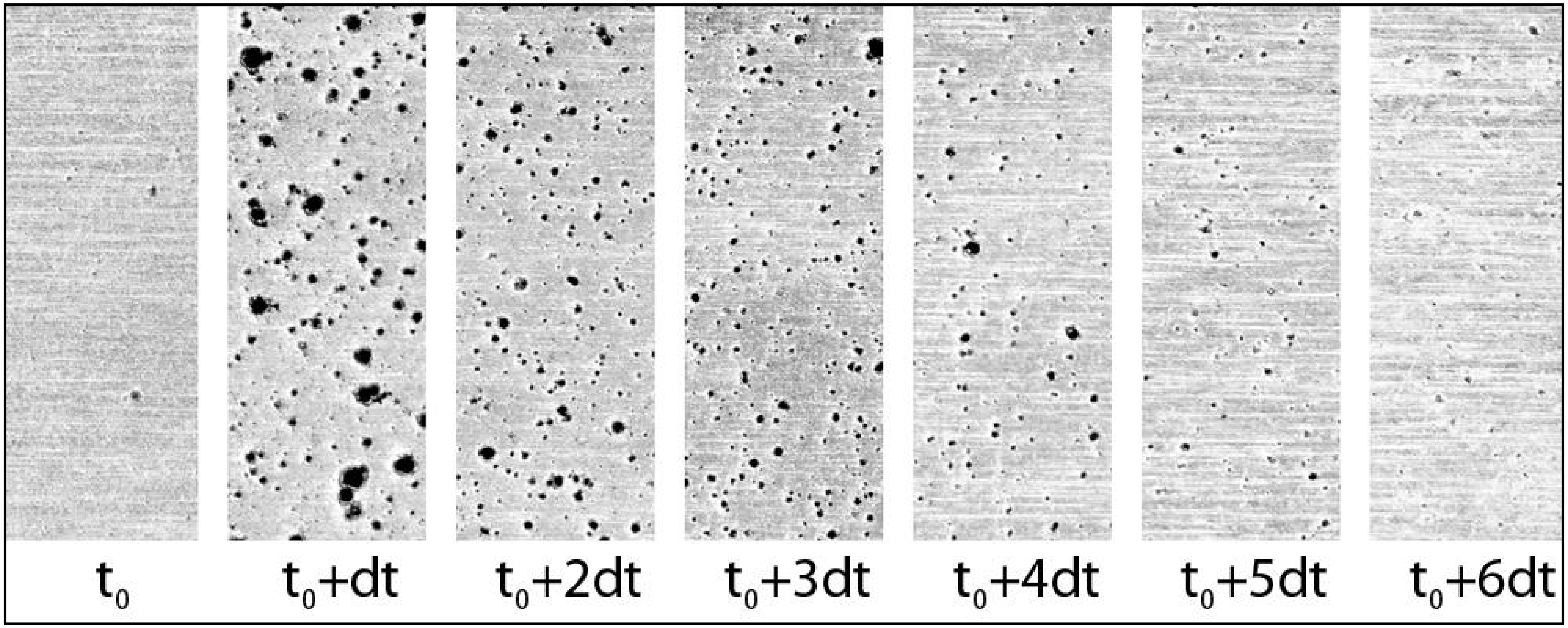
rticle Streak Recorder (PSR)



- Uses a rotating disc behind a thin aperture
  - Thin aluminum on a high-density foam core attached to an aluminum hub
  - Different RPM's used at different standoffs to account for differences in blast duration
- Provides a measure of the time history of the number density of particles
  - Can be used to estimate momentum flux given assumptions about the time dependence



al Data from Particle Streak Recorders



- The PSR data records give a measure of the time history of particle number density passing through the aperture
  - Normally expressed as number of particles per unit area
  - Errors arise when multiple particles produce a single hole
- Also provides statistics on hole sizes
  - Relationship to actual particle sizes is difficult to define

R Impact Surface Analysis Technique

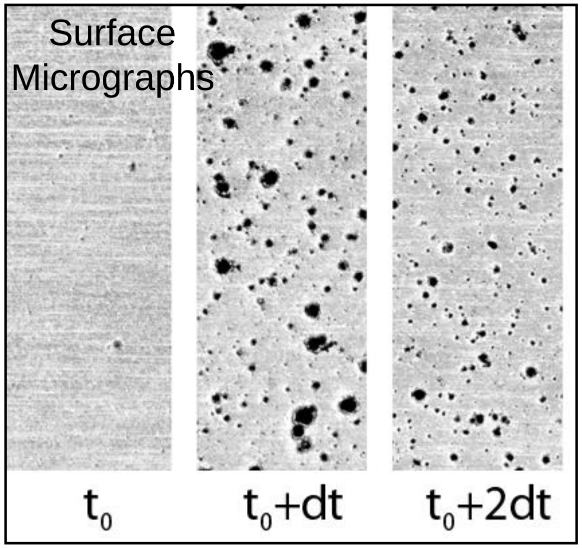
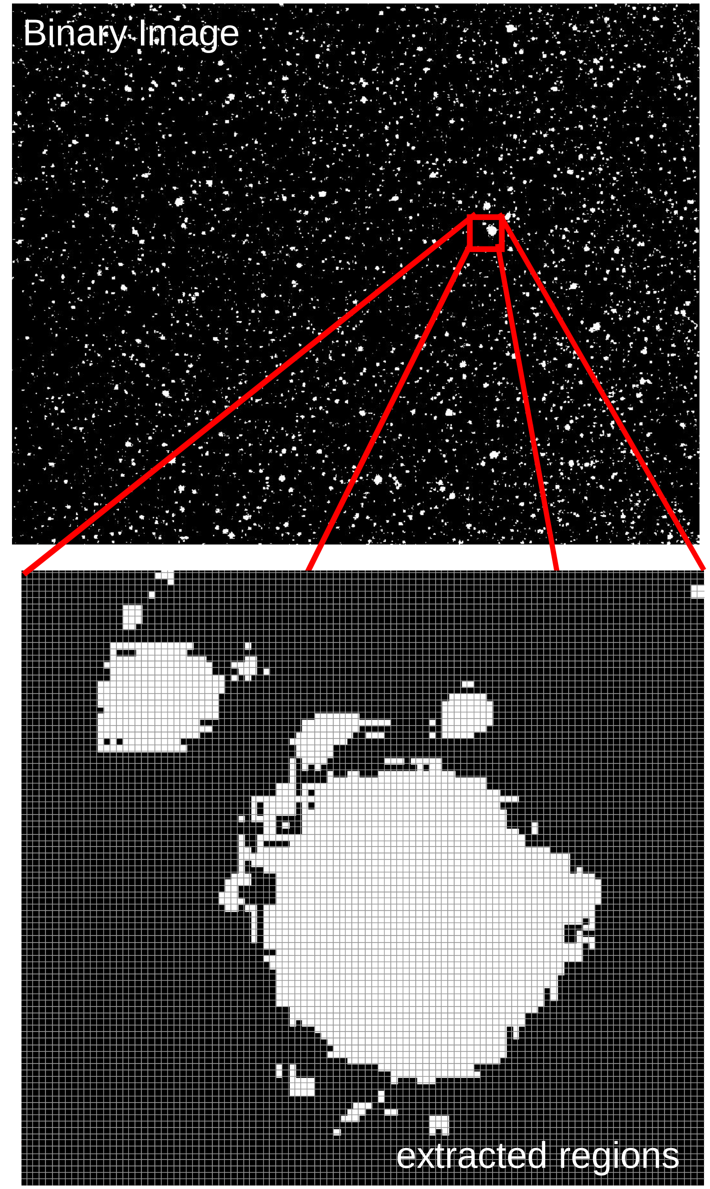
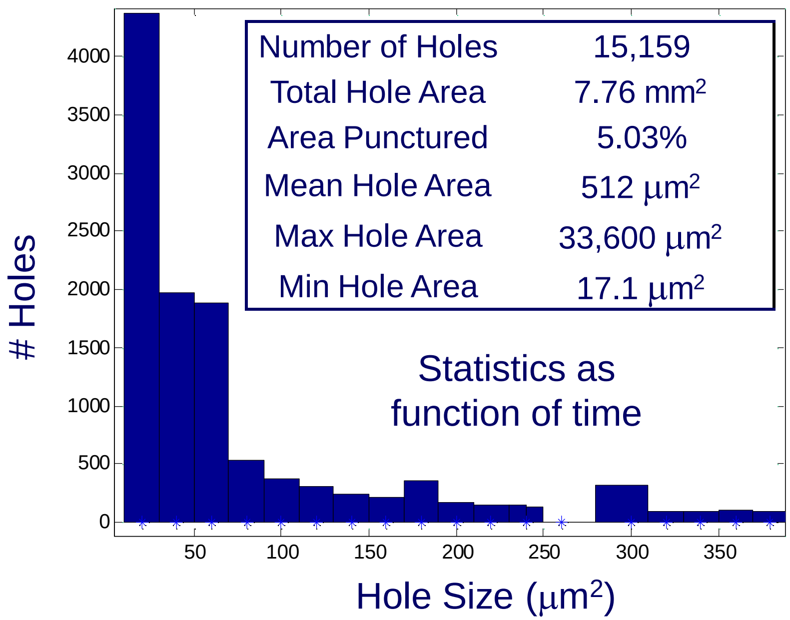


Image processing algorithm implemented in Matlab



Connectivity algorithm implemented in Matlab

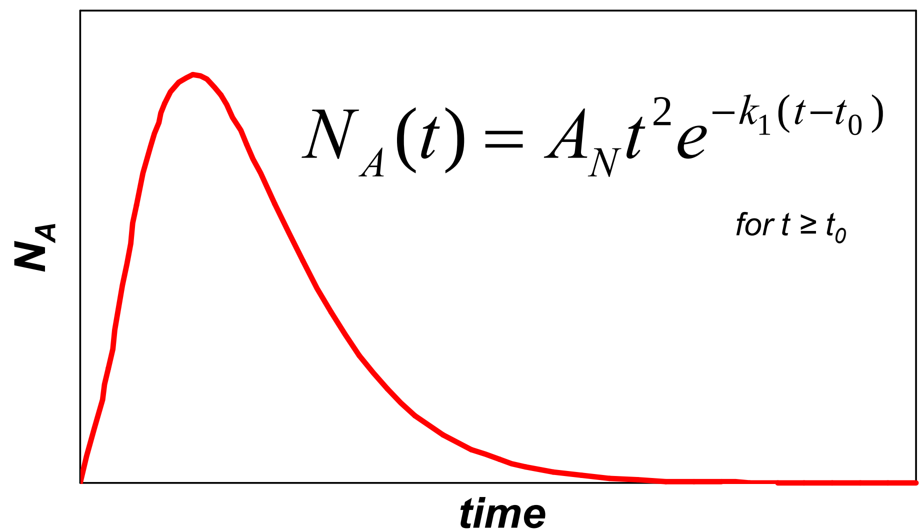


Data Analysis Procedure

- Momentum flux rate is simply the mass per particle times the average particle speed times number density flux rate

$$\frac{dp_A}{dt} = m_p V_p \frac{dN_A}{dt}$$

- Data from a number of tests show that the number density flux has a modified decaying exponential behavior
  - t^2 term accounts for behavior at the front of the particle wave



- Particle speed is calculated based on arrival time and allowed to decay exponentially

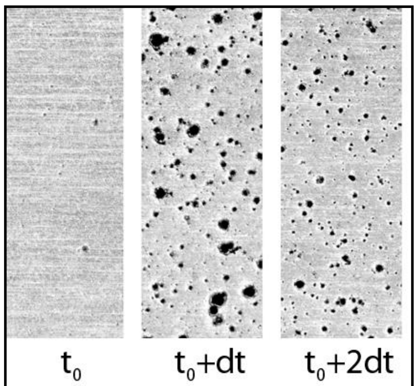
$$V_p = \frac{d}{t} e^{-k_2(t-t_0)} \quad \text{for } t \geq t_0$$

Data Analysis Procedure

The data analysis procedure then reduces to finding four parameters:

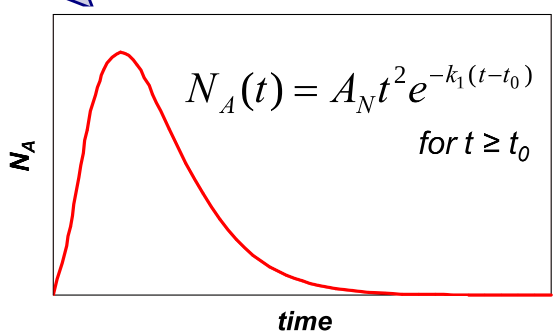
A_N, k_1, k_2, and t_0

A_N

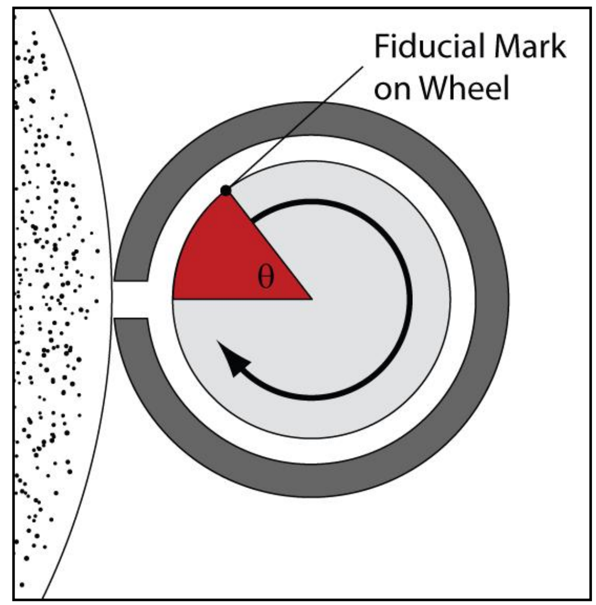


k_1

The values of A_N and k_1 are determined by fitting the PSR data to the modified exponential model



t_0



A fiducial provides a relationship between angular position around the wheel surface and time

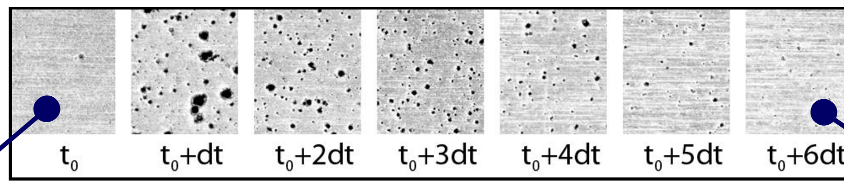
Data Analysis Procedure

The data analysis procedure then reduces to finding four parameters:

A_N, k_1, k_2, and t_0

k_2

For a given particle material and PSR surface material, the minimum marking speed V_{min} can be estimated.



First appearance of particles: t_0

Last evidence of particles: t_1

The estimate for V_{min} along with measurements of t_0 and t_1 will give the particle velocity decay constant k_2.

$$V_p = \frac{d}{t} e^{-k_2(t-t_0)} \Rightarrow V_{min} = \frac{d}{t_1} e^{-k_2(t_1-t_0)} \Rightarrow k_2 = \frac{1}{t_0 - t_1} ln\left(\frac{V_{min} t_1}{d}\right)$$

ing the Impulse from the PSR Data

- Once the constants A_N, k_1, k_2, and t_0 are determined, the solid-phase impulse can be computed
- The impulse (per unit area) is the time integral of the momentum flux rate
  - Assumes particle impacts are perfectly plastic
- Given the total impulse measurement from the Unconfined Momentum Trap, the difference between the two is the gas-phase impulse
  - Note that these values are usually normalized to surface area

$$I_{A,SP} = \int_{t_0}^{\infty} \frac{dp_A}{dt} dt$$

$$I_{A,SP} = \frac{m_p dA_N \left[1 + (k_1 + k_2) t_0\right]}{(k_1 + k_2)^2}$$

$$I_{A,tot} = I_{A,GP} + I_{A,SP}$$

From momentum trap

From PSR

Wrap-Up and Summary

erview of Techniques

Diagnostic Technique	Time varying?	Separates loads by phase?	Measurement Fidelity
Unconfined Momentum Trap	No	No – total only	High
Confined Momentum Trap	No	Yes	Moderate
Inverted Ballistic Pendulum	No	Yes	Moderate
Cantilevered Ball Gauge	No	No – total only	Low
Hopkinson Pressure Bar	Yes	No – total only	Moderate
Particle Streak Recorder	Yes	No – solid phase only	Low

- This presentation has given an introduction to the state-of-the art in multiphase blast diagnostic techniques
- These techniques are generally time-integrated
  - Time-varying measurement techniques for solid-phase loads are relatively immature
- Improvements in hole detection will allow increases in the fidelity of the Particle Streak Recorder Technique
  - Currently investigating alternate impact surface configurations to enable higher signal-to-noise ratio